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**Results from the Caliban Criticality Accident Dosimetry Exercise,
September 2010 (U)**

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INTRODUCTION

In September 2010, three Health Physics Services individuals from Savannah River Site (SRS) participated in a criticality accident dosimetry exercise at Commissariat À L'énergie Atomique Et Aux Énergies Alternatives (CEA) Valduc, France. The exercise was funded by the U.S. Department of Energy Nuclear Criticality Safety Program and coordinated through Lawrence Livermore National Laboratory (LLNL). Other facilities represented included LLNL, Pacific Northwest National Laboratory, Y-12, Los Alamos National Laboratory (LANL), and Oak Ridge National Laboratory (ORNL).

The exercise was conducted using the CALIBAN reactor, which is a fast burst assembly made of highly enriched uranium, operated in the pulse mode (Trompier, et. al., 2008¹). The exposures were performed as single blinds where the participants were not informed of the dose to be delivered. Participants were informed of the assembly, shielding, and operating mode (pulse, free evolution, or steady state). Participants were free to select the placement of their dosimetry materials according to the radial distance from the center axis of the assembly, orientation to the assembly, and whether or not they were placed on a phantom. For both exposures the CALIBAN assembly was operated in pulse mode with no shielding. The number of fissions, or assembly power output, was the only difference between the two exposures. On the last day of the exercise participants were requested to submit their preliminary dose estimates to CEA Valduc. The results from all participants were compiled and compared with the estimated delivered neutron and gamma absorbed doses. The estimated doses were calculated by CEA Valduc based on calibration information for CALIBAN and the measured number of fissions

The goals for SRSs participation were:

- Test the accuracy of the neutron dose algorithm which is described in the Savannah River Site Criticality Dosimetry Technical Basis Manual, WSRC-IM-96-145²,
- Determine the cause of the high gamma dose results from the 2009 intercomparison exercise, SILENE Criticality Accident Dosimetry Exercise, Oct 2009, SRNS-STI-2010-00372³.
- Evaluate the use of the Canberra Falcon 5000 Portable HPGe Spectrometer and the Thermal Eberline HandECount alpha beta sample counter.

BACKGROUND

The Caliban Reactor

The Caliban reactor is located at CEA Valduc outside of Dijon, France. Built in 1971, the reactor is an unreflected highly enriched uranium (HEU) metal fast burst reactor. The reactor consists of two 5 disc assemblies and 4 control rods. The reactor is used to produce a pulse similar to that of a typical metal criticality accident. The reactor is located in a 5 meter x 8 meter x 10 meter room.

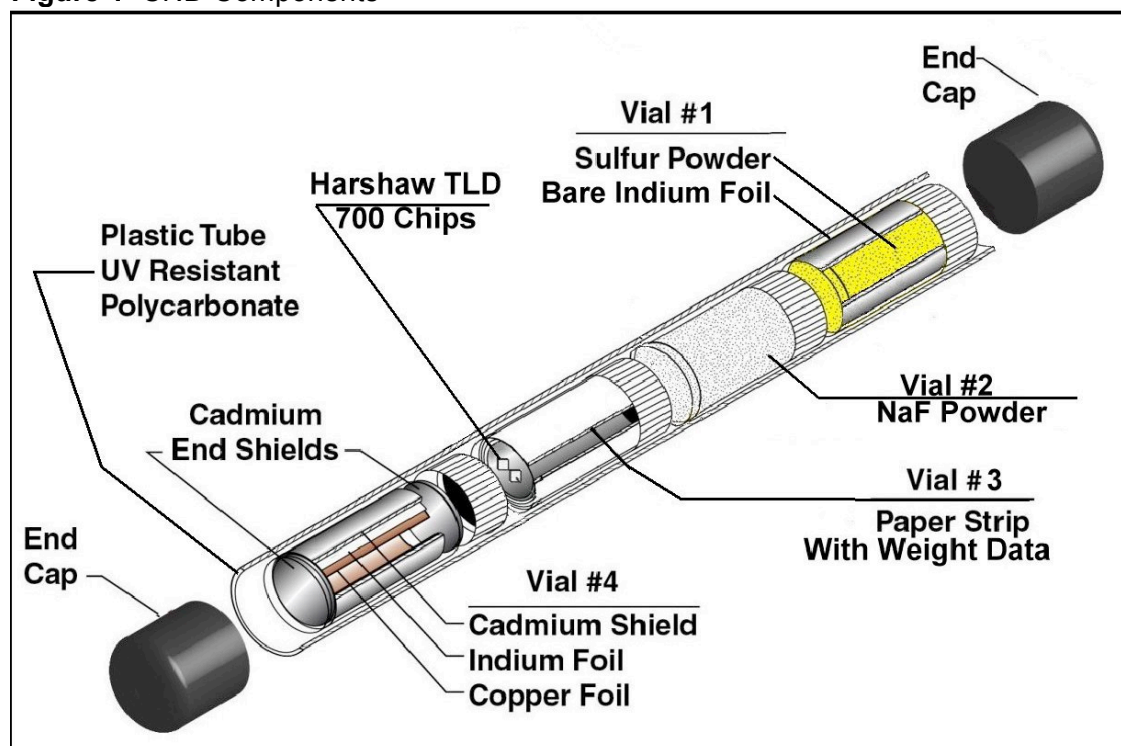
To initiate a power excursion, the HEU control rods are inserted into the holes in the discs to a predetermined supercritical level. When the excursion has occurred, the material is separated ending the reaction.

SRS Nuclear Accident Dosimeter

At SRS the Nuclear Accident Dosimeter is referred to as a Criticality Neutron Dosimeter (CND). The design of the CND is described in detail in The Savannah River Site Criticality Dosimetry Technical Basis Manual, WSRC-IM-96-145.

The CND contains four vials containing activation foils, activation powders, listing of weights, and two Harshaw TLD-700 chips (Figure 1).

Figure 1 CND Components



The CND's components are assembled in a 3-5/8 inch long by 1/2 inch diameter polycarbonate tube. A clip is attached so it can be attached to the wearer's lanyard. Indium, copper, and cadmium foils were shaped into hollow cylinders to lessen directional effects. These foils, along with specific amounts of sodium fluoride, sulfur and TLD-700 chips, are contained in four small polystyrene vials. These materials are pre-weighed to expedite processing after an accident. The exact weights of all the activation materials are listed on a slip of paper which is placed in one of the polyethylene vials. Two Harshaw TLD-700 lithium fluoride chips are contained in one of the polyethylene vials. The CND components are listed in Table 1.

Table 1 CND Components:

Vial No.	Material Contained	~Size (in.) or Weight (g)
1	Cadmium shield	1 piece of 1 x 5/8 x 1/32 in. 2 pieces of 3/8 dia. x 1/32 in.
	Indium foil (Cd-covered)	15/16 x 5/8 x 0.005 in.
	Copper foil (Cd-covered)	15/16 x 5/8 x 0.005 in.
2	Sodium fluoride powder	1.50 gram ± .20 gm
3	Indium foil (bare foil around outside of sulfur vial)	1 7/16 x 5/8 x 0.005 in.
	Sulfur powder	1.00 gram ± .20 gm
4	Paper with weight data (not shown)	~1.2 x 5/8 in.
	Harshaw TLD-700 chips	2 chips

The reactions of interest for each CND component are shown in Table 2

Table 2 Activation Reactions

Neutron Energy	Reaction	Half-Life	Foil/Powder	Count Method	Analysis
Thermal*	$^{115}\text{In}(n,\gamma)^{116\text{m}}\text{In}$	54 min	Bare In Foil	HandECCount	β
Epi-thermal*	$^{115}\text{In}(n,\gamma)^{116\text{m}}\text{In}$	54 min	Cd covered In Foil	HandECCount	β
Thermal**	$^{113}\text{In}(n,\gamma)^{114\text{m}}\text{In}$	49.5 day	Bare In Foil	HandECCount	β
Epi-thermal**	$^{113}\text{In}(n,\gamma)^{114\text{m}}\text{In}$	49.5 day	Cd covered In Foil	HandECCount	β
2 ev – 1MeV	$^{63}\text{Cu}(n,\gamma)^{64}\text{Cu}$	12.7 hr	Copper	HandECCount	β
1MeV – 2.9 MeV	$^{115}\text{In}(n,n')^{115\text{m}}\text{In}$	4.5 hr	Bare In foil	Falcon 5000	γ 336 keV
>2.9 MeV	$^{32}\text{S}(n,p)^{32}\text{P}$	14.3 day	Sulfur Powder	HandECCount	β
N/A	$^{23}\text{Na}(n,\gamma)^{24}\text{Na}$	15.0 hr	NaF Powder	Falcon 5000	γ 1.37 & 2.76 MeV

* Sample count if <10 hours of irradiation

**Sample count if >20 hours of irradiation

Previous Exercises

SRS participated in numerous DOE intercomparisons at the Health Physics Research Reactor (HPRR) at Oak Ridge National Laboratory until the HPRR unit was shut down in 1986. The SRS CND performed well in these exercises. After the HPRR was shut down, the number of exercises was greatly reduced. In 1993 and in 2003, SRS participated in an international intercomparison in Valduc, France. In 1995, SRS participated in a DOE intercomparison at Los Alamos National Laboratory. In 2009 SRS participated in a DOE sponsored exercise in Valduc, France. The basic fluence and dose conversion factors developed in 1986 have been adjusted to improve response to various spectra; however the basic methodology and algorithm have remained the same.

METHODS

Prior to the exercise, CNDs were fabricated from new materials. To facilitate comparisons, all of the CND components consisted of the same mass and geometries.

Table 3 contains the data on component mass of the CNDs.

Table 3 CND Mass (Grams)

CND	1	2	3	4	5	6	7	8	Average Mass (g)	Range
NaF	1.494	1.484	1.480	1.478	1.480	1.486	1.460	1.459	1.478 ± .019	1.26%
S	1.003	0.998	1.001	1.000	1.001	1.003	1.003	1.004	1.002 ± .004	0.36%
Cu	0.439	0.440	0.440	0.441	0.440	0.441	0.439	0.440	0.440 ± .001	0.20%
In-Cd	0.481	0.480	0.480	0.480	0.480	0.481	0.480	0.480	0.480 ± .001	0.25%
In-B	0.481	0.480	0.480	0.480	0.480	0.481	0.480	0.480	0.480 ± .001	0.25%

During the week of September 20, 2010, two unshielded pulse irradiations were performed at the Caliban reactor. The first pulse was performed on September 21, 2010 at 11:11:32 and the second pulse was initiated on September 22 at 11:13:02.

For both exposures, two CNDs were taped together and placed on the front of the small phantom and two CNDs were taped together placed on the rear of the small phantom. The phantom was located 4 meters distance from the reactor center line.

After each exposure the CNDs were allowed to decay to safe levels before being given to participants for analysis. The CNDs were disassembled and activated materials were placed in plastic trays while awaiting counting. Sulfur powder, NaF powder, Copper foil, and Indium foils were placed in planchets for beta counting using two ThermoEberline HandECount alpha beta scintillation detectors. Gamma emissions from the bare and cadmium shielded Indium foils were counted using a Canberra Falcon 5000 electronically cooled high purity germanium detector. The counting equipment was calibrated at the Savannah River Site prior to transport to France. Verification checks in France were performed using check sources provided by LLNL and Valduc.

In the 2009 exercise at the Silene reactor, the SRS gamma doses were much higher than the reference gamma doses. Discrepancies in gamma doses were also noted by several other participants. For this exercise, three Harshaw TLD-700 chips were used in each CND. The Harshaw TLD-700 chips were counted at SRS using a calibrated Panasonic UD-513A gas heated thermoluminescence reader.

The neutron activation results, sample weights, and time since criticality for each CND component were entered into an Excel spreadsheet to calculate results.

RESULTS

The averaged dose results for each exposure are provided in Table 3. In most cases, activated components were counted twice and the results averaged for the final neutron dose.

Table 3 CND Results Summary

Run	CND #	Location	Delivered		SRS		Relative Bias (%)	
			Neutron Dose (rad)	Gamma Dose (rad)	Neutron Dose (rad)	Gamma Dose (rad)	Neutron	Gamma
1	1	4 m Phantom (Front)	170	40	169	109	-2	173
	2				181	109	7	173
	3	4 m Phantom (Rear)			158	130	-7	225
	4				170	129	0	223
2	5	4 m Phantom (Front)	240	60	281	129	17	115
	6				265	136	10	127
	7	4 m Phantom (Rear)			253	154	5	157
	8				265	138	10	130

Neutron Dose Results

The neutron dose results for the first exposure were within 7% of the delivered dose and the neutron dose results for the second exposure were within 17% of the delivered dose. Although the total neutron doses were within 25% of the delivered neutron dose, the doses calculated from the copper foils (2eV to 1 MeV) were higher than the Caliban spectrum indicated and the doses calculated from the indium foils (1 to 3 MeV) were lower than the Caliban spectrum indicated. Some of the count data for the #5 CND were inconclusive so only one neutron dose calculation was performed for that CND. As activated Indium foil has two beta decay paths for low energy neutron activation, the dose algorithm also has two paths based on the decay time. The Indium foils were double counted with < 10 hours decay time and were double counted again at > 20 hours decay time. Neutron doses by energy group are contained in Table 4 and Table 5. Neutron dose fraction by energy range is listed in Table 6.

Table 4 CND Neutron Dose Details; 1st Exposure
(CND components were counted twice and the results averaged for final dose)

CND #	1		2		3		4	
Count	1st	2nd	1st	2nd	1st	2nd	1st	2nd
0 - 0.4 eV	0.83	-0.27	0.98	0.21	2.8	1.15	2.95	0.98
0.4 - 2 eV	0.03	0.28	0.03	0.19	0.05	0.29	0.06	0.3
2 eV - 1 MeV	92	95	102	95	125	130	126	138
1 MeV - 3 MeV	42	31	53	38	18	13	23	14
> 3 MeV	42	35	36	36	12	13	19	16
Total	177	161	192	169	158	157	171	169
Average	169		181		158		170	

Table 5 CND Neutron Dose Details; 2nd Exposure

(CND components were counted twice and the results averaged for final dose)
(Some of the count data from CND #5 were lost)

CND #	5	6	7	8
Count	1st	1st 2nd	1st 2nd	1st 2nd
0 - 0.4 eV	0.25	0.85 0.30	3.24 1.02	3.73 1.31
0.4 - 2 eV	0.26	0.04 0.28	0.07 0.43	0.08 0.45
2 eV - 1 MeV	131	137 132	182 179	212 204
1 MeV - 3 MeV	98	57 72	27 65	25 38
> 3 MeV	51	78 53	29 18	24 22
Total	281	273 258	241 263	265 266
Average	281	265	252	265

Table 6 CND Neutron Dose Fraction by Energy Group (4 meters)

Orientation	Front		Rear		Front		Rear	
CND #	1	2	3	4	5	6	7	8
0 - 2 eV	0.003	0.004	0.014	0.002	0.002	0.003	0.009	0.011
2 eV - 1 MeV	0.55	0.54	0.81	0.78	0.47	0.51	0.72	0.78
1 MeV - 3 MeV	0.22	0.25	0.10	0.11	0.35	0.24	0.18	0.12
> 3 MeV	0.23	0.20	0.08	0.10	0.18	0.25	0.09	0.09

Gamma Dose Results

Although two Harshaw TLD 700 chips are used in the standard CND, three chips were used in this exercise. With the exception of the #5 CND, all of the three chips in each CND were within 10% of each other. The TLD 700 gamma dose results were substantially higher than the delivered gamma doses from the irradiation. As seen in Table 3, the over response ranged from 115% to 225%. Table 7 contains the individual raw gamma dose results (uncorrected for exposure orientation on phantom).

Table 7 TLD Chip Raw Gamma Dose Results
(Uncorrected for exposure orientation)

		CND#	Chip 1	Chip 2	Chip 3	Ave (Rad)	Range
Run 1	Front	1	159	156	152	156 ± 04	2.6%
		2	164	151	149	155 ± 09	5.8%
	Rear	3	127	139	125	130 ± 09	6.9%
		4	134	114	139	129 ± 15	7.8%
Run 2	Front	5	188	160	206	185 ± 25	13.5%
		6	196	194	193	194 ± 02	1.0%
	Rear	7	150	156	156	154 ± 04	2.6%
		8	129	151	134	138 ± 13	9.4%

Background	#1	#2	#3	#4	#5	Ave
Controls	0	0	0	0	0	0

DISCUSSION

All CNDs were exposed at 4 meters. Two CNDs of identical component weights were taped together and placed on the phantom. For each exposure two CNDs were taped to the front of the phantom and two CNDs were taped to the rear of the phantom. The purpose of this configuration was to allow for the examination of counting statistics of the ThermoEberline HandECOUNT and the Falcon 5000. These instruments are being evaluated as backups to current laboratory equipment. In the event of loss of power during an accident, the normal laboratory equipment used to count the activated foils and powders would not be available. The ThermoEberline HandECOUNT and the Falcon 5000 are both portable and can operate on battery power.

In order to effectively evaluate the count data, all count data were decay corrected to T_0 . Appendix A contains the Falcon 5000 counting data and Appendix B contains the ThermoEberline HandECOUNT counting data.

As evidenced in Appendix A, the counting of the 336 keV peak from the ^{115}In foils was problematic due to its short 4.5 hour half-life and interference from ^{116}In . The counting times should have been longer. Due to time constraints of the exercise, follow-up counting of questionable results could not be performed.

While the ^{115}In results are corrected back to time T_0 prior to entering the data in the dose calculation software, the beta counts results are not corrected back to T_0 prior to entering into the dose calculation software. Because of this, discrepancies in beta counting are not easily identified. As noted in Appendices A and B, many of the counting results were greater than 20% of the averaged results. If a criticality were to occur at SRS, procedures require back to back sample counting. The back to back counting method would help identify discrepancies and allow additional counts to be performed if a sample count was questionable.

Gamma dose results were much higher than reported delivered dose. After each exposure the CNDs were stored (~ 2 hours) with other activated NADs until distribution to personnel for disassembly and counting. In addition, the configuration of the SRS CND places the vial containing the Harshaw TLD-700 chips adjacent the vial containing the activated cadmium shielding. This could also have contributed to gamma dose to the TLD 700 chips. It is not known how much additional gamma dose was accumulated during the storage time. In future exercises, unexposed TLD-700 chips should be placed in the post exposure NAD storage container to determine how much dose is accumulated during the decay of activated components.

CONCLUSION

The neutron dose results were within the $\pm 25\%$ specified by ANSI N13.3-1969⁴, however, the gamma doses were much higher than expected. At SRS, the Harshaw TLD-700 chips are not the only source for determining gamma dose. The individual's TLD badge will also be read and that dose can be compared to the results of the Harshaw TLD-700 chips. In future exercises control Harshaw TLD 700 chips will be used as well as UD-812 TLDs.

The Canberra Falcon 5000 Portable HPGe Spectrometer and the Thermal Eberline HandECOUNT alpha beta sample counter proved to be effective alternatives to laboratory counting room equipment. In the event of a loss of site power or a requirement to locate off site,

this equipment would provide accurate counting of activated components and neutron doses could be calculated.

REFERENCES

¹Trompier,F.; Huet,C.; Medioni,R.; Robbes,I.; Asselineau,B. Dosimetry of the Mixed Field Irradiation Facility CALIBAN. Radiation Measurements.43: 1077 1080. 2008.

²Savannah River Site Criticality Dosimetry Technical Basis Manual, WSRC-IM-96-145,

³SILENE Criticality Accident Dosimetry Exercise, Oct 2009, SRNS-STI-2010-00372

⁴ANSI, Dosimetry for Criticality Accidents, ANSI 13.3, American National Standards Institute, Inc., New Your, New York, 1969.

Appendix A Indium Foil Counting Results from the Falcon 5000

CNDs 1 & 2 (Front of Small Phantom)									
CND	File Name	Foil Activity (uCi)	Activity Uncertainty	ΔT (Hours)	pCi @ To	foil wt	pCi/gram @ To	Average	% Diff
1	SRS_LgIn_100921_153815 (bare)	6.16E-03	31.1%	4.45	1.22E+04	0.4812	2.54E+04	3.095E+04	-18%
	SRS_LgIn_100921_151346 (InCd)	8.44E-03	10.8%	4.02	1.57E+04	0.4812	3.27E+04		6%
2	SRS_LgIn_100921_155719 (InCd)	8.37E-03	11.1%	4.76	1.75E+04	0.4804	3.64E+04		18%
	SRS_LgIn_100921_154758 (bare)	6.91E-03	25.4%	4.61	1.41E+04	0.4804	2.93E+04		-5%

CNDs 3 & 4 (Rear of Small Phantom)									
CND	File Name	Foil Activity (uCi)	Activity Uncertainty	ΔT (Hours)	pCi @ To	foil wt	pCi/gram @ To	Average	% Diff
3	SRS_LgIn_100921_162947 (InCd)	1.99E-03	29.5%	5.30	4.52E+03	0.4802	9.40E+03	9.761E+03	-4%
	SRS_LgIn_100921_162129 (bare)	1.73E-03	45.5%	5.17	3.84E+03	0.4802	8.00E+03		-18%
4	SRS_LgIn_100921_164423 (InCd)	2.64E-03	16.2%	5.55	6.22E+03	0.4803	1.30E+04		33%
	SRS_LgIn_100921_170006 (bare)	1.70E-03	47.4%	5.81	4.17E+03	0.4803	8.68E+03		-11%

CNDs 5 & 6 (Front of Small Phantom)									
CND	File Name	Foil Activity (uCi)	Activity Uncertainty	ΔT (Hours)	pCi @ To	foil wt	pCi/gram @ To	Average	% Diff
5	SRS_LgIn_100922_145211 (InCd)	1.66E-02	17.9%	3.65	2.92E+04	0.4801	6.08E+04	5.33E+04	14%
	SRS_LgIn_100923_122050 (InCd)	6.89E-04	12.1%	25.13	3.35E+04	0.4801	6.97E+04		31%
	SRS_LgIn_100923_114219 (bare)	6.77E-04	22.6%	24.49	2.98E+04	0.4801	6.20E+04		16%
6	SRS_LgIn_100922_150212 (InCd)	1.24E-02	26.1%	3.82	2.24E+04	0.4808	4.65E+04		-13%
	SRS_LgIn_100923_105550 (InCd)	6.28E-04	17.9%	23.71	2.45E+04	0.4808	5.09E+04		-4%
	SRS_LgIn_100922_145810 (bare)	8.99E-03	36.8%	3.59	1.56E+04	0.4808	3.25E+04		-39%
	SRS_LgIn_100923_102218 (bare)	6.78E-04	17.0%	23.15	2.43E+04	0.4808	5.05E+04		-5%

CNDs 7 & 8 (Rear of Small Phantom)									
CND	File Name	Foil Activity (uCi)	Activity Uncertainty	ΔT (Hours)	pCi @ To	foil wt	pCi/gram @ To	Average	% Diff
7	SRS_LgIn_100922_153110 (InCd)	4.06E-03	23.9%	4.30	7.89E+03	0.4802	1.64E+04	2.15E+04	-24%
	SRS_LgIn_100923_111806 (InCd)	----	----	----	----	----	----		----
	SRS_LgIn_100922_151439 (bare)	----	----	----	----	----	----		----
	SRS_LgIn_100923_100641 (bare)	3.38E-04	26.1%	22.89	1.16E+04	0.4802	2.42E+04		13%
8	SRS_LgIn_100922_155207 (InCd)	3.39E-03	28.9%	4.65	6.96E+03	0.4800	1.45E+04		-33%
	SRS_LgIn_100923_104551 (InCd)	4.20E-04	37.2%	23.55	1.60E+04	0.4800	3.33E+04		55%
	SRS_LgIn_100922_153535 (bare)	4.66E-03	53.0%	4.38	9.16E+03	0.4800	1.91E+04		-11%
	SRS_LgIn_100923_103403 (bare)	----	----	----	----	----	----		----

Appendix B Beta Counting Results

1st Exposure

CND	Count	Material	Unit wt	Delta T	dpm	Counter	Counter Correction	dpm/g @ T=0	Averaged dpm/gram @ To	% Difference
1	1	Bare In<10	0.4812	243.5	8.08E+06	B	0.96	3.65E+08	4.02E+08	-9.31
	2	Bare In<10	0.4812	385.5	1.56E+06	B	0.96	4.33E+08		7.70
2	1	Bare In<10	0.4804	262.5	6.63E+06	B	0.96	3.82E+08		-4.96
	2	Bare In<10	0.4804	401.5	1.25E+06	B	0.96	4.28E+08		6.57
1	3	Bare In>20	0.4812	1373.5	2.50E+03	A	1.00	5.26E+03	5.46E+03	-3.61
	4	Bare In>20	0.4812	1381.5	2.83E+03	B	0.96	5.73E+03		4.95
2	3	Bare In>20	0.4804	1393.5	2.51E+03	A	1.00	5.30E+03		-2.80
	4	Bare In>20	0.4804	1480.5	2.73E+03	B	0.96	5.54E+03		1.46
1	1	Cd In<10	0.4812	229.5	1.25E+06	A	1.00	4.91E+07	5.44E+07	-9.61
	2	Cd In<10	0.4812	398.5	1.55E+05	A	1.00	5.27E+07		-3.05
2	1	Cd In<10	0.4804	287.5	6.93E+05	B	1.00	5.72E+07		5.16
	2	Cd In<10	0.4804	408.5	1.57E+05	B	0.96	5.84E+07		7.49
1	3	Cd In>20	0.4812	1371.5	1.93E+03	B	0.96	3.90E+03	3.74E+03	4.46
	4	Cd In>20	0.4812	1381.5	1.75E+03	A	1.00	3.69E+03		-1.28
2	3	Cd In>20	0.4804	1403.5	1.77E+03	A	0.96	3.58E+03		-4.11
	4	Cd In>20	0.4804	1487.5	1.86E+03	B	0.96	3.77E+03		0.94
1	1	Cu	0.4391	239.5	7.87E+03	A	1.00	2.22E+04	2.35E+04	-5.34
	2	Cu	0.4391	383.5	7.54E+03	A	1.00	2.43E+04		3.27
	3	Cu	0.4391	1438.5	2.73E+03	A	1.00	2.28E+04		-2.96
	4	Cu	0.4391	1497.5	2.88E+03	B	0.96	2.44E+04		3.76
2	1	Cu	0.4402	279.5	8.39E+03	B	0.96	2.36E+04		0.41
	2	Cu	0.4402	365.5	7.95E+03	B	0.96	2.41E+04		2.78
	3	Cu	0.4402	1449.5	2.93E+03	B	0.96	2.37E+04		0.82
	4	Cu	0.4402	1538.5	2.51E+03	A	1.00	2.28E+04		-2.74
1	1	S	1.003	236.5	1.75E+03	B	0.96	1.70E+03	1.55E+03	9.14
	2	S	1.003	352.5	1.72E+03	B	0.96	1.67E+03		7.59
	3	S	1.003	1434.5	1.50E+03	B	0.96	1.51E+03		-2.97
	4	S	1.003	1522.5	1.38E+03	A	1.00	1.45E+03		-6.46
2	1	S	0.998	No Count	Data					
	2	S	0.998	358.5	1.50E+03	A	1.00	1.52E+03		-2.34
	3	S	0.998	1430.5	1.43E+03	A	1.00	1.50E+03		-3.43
	4	S	0.998	1504.5	1.51E+03	B	0.96	1.53E+03		-1.54

Appendix B Beta Counting Results (continued)

1st Exposure

CND	Count	Material	Unit wt	Delta T	dpm	Counter	Counter Correction	dpm/g @ T=0	Averaged dpm/gram @To	% Difference
3	1	Bare In<10	0.4802	296.5	3.10E+06	B	0.96	2.76E+08	2.93E+08	-5.65
	2	Bare In<10	0.4802	415.5	7.47E+05	B	0.96	3.05E+08		4.12
4	1	Bare In<10	0.4803	335.5	2.03E+06	B	0.96	2.97E+08		1.52
	2	Bare In<10	0.4803	No Count Data						
3	3	Bare In>20	0.4802	1393.5	1.72E+03	B	0.96	3.49E+03	3.25E+03	7.41
	4	Bare In>20	0.4802	1492.5	1.43E+03	A	1.00	3.03E+03		-6.93
4	3	Bare In>20	0.4803	1412.5	1.68E+03	B	0.96	3.40E+03		4.66
	4	Bare In>20	0.4803	1447.5	1.46E+03	A	1.00	3.08E+03		-5.13
3	1	Cd In<10	0.4802	305.5	3.46E+05	B	0.96	3.46E+07	3.54E+07	-2.23
	2	Cd In<10	0.4802	422.5	8.08E+04	B	0.96	3.61E+07		2.04
4	1	Cd In<10	0.4803	316.5	3.08E+05	B	0.96	3.54E+07		0.19
	2	Cd In<10	0.4803	No Count Data						
3	3	Cd In>20	0.4802	1403.5	9.61E+02	B	0.96	1.95E+03	1.92E+03	1.50
	4	Cd In>20	0.4802	1500.5	8.83E+02	A	1.00	1.87E+03		-2.90
4	3	Cd In>20	0.4803	1418.5	1.00E+03	B	0.96	2.04E+03		5.93
	4	Cd In>20	0.4803	1515.5	8.68E+02	A	1.00	1.83E+03		-4.53
3	1	Cu	0.4396	327.5	4.20E+03	A	1.00	1.28E+04	1.37E+04	-6.44
	2	Cu	0.4396	390.5	4.42E+03	A	1.00	1.43E+04		4.23
	3	Cu	0.4396	1447.5	1.48E+03	A	1.00	1.25E+04		-9.15
	4	Cu	0.4396	1512.5	1.58E+03	B	0.96	1.35E+04		-1.23
4	1	Cu	0.4405	329.5	4.46E+03	B	0.96	1.31E+04		-4.45
	2	Cu	0.4405	338.5	5.10E+03	A	1.00	1.57E+04		14.59
	3	Cu	0.4405	1441.5	1.79E+03	B	0.96	1.43E+04		4.63
	4	Cu	0.4405	1530.5	1.49E+03	A	1.00	1.34E+04		-2.19
3	1			No Count Data						
	2	S	1.001	372.5	3.54E+02	A	1.00	3.58E+02	3.91E+02	-8.41
	3	S	1.001	1454.5	3.22E+02	A	1.00	3.38E+02		-13.70
	4	S	1.001	1524.0	3.85E+02	B	0.96	3.89E+02		-0.45
4	1	S	1.000	315.5	5.80E+02	A	1.00	5.86E+02		49.70
	2	S	1.000	379.5	4.00E+02	A	1.00	4.05E+02	3.50	
	3	S	1.000	1462.5	3.65E+02	A	1.00	3.84E+02	-1.91	
	4	S	1.000	1471.5	4.69E+02	B	0.96	4.73E+02	20.98	

Appendix B Beta Counting Results (continued)

2nd Exposure

CND	Count	Material	Unit wt	Delta T	dpm	Counter	Counter Correction	dpm/g @ T=0	Averaged dpm/gram @T ₀	% Difference
5	1	Bare In<10	0.4801	202	1.38E+07	A	1.00	3.81E+08	4.72E+08	-19.28
	2	Bare In<10	0.4801	355	2.79E+06	A	1.00	5.46E+08		15.75
6	1	Bare In<10	0.4808	201	1.50E+07	B	0.96	3.94E+08		-16.47
	2	Bare In<10	0.4808	369	2.53E+06	B	0.96	5.66E+08		20.00
5	3	Bare In>20	0.4801	1364	3.42E+03	A	1.00	7.21E+03	7.43E+03	-2.90
6	3	Bare In>20	0.4808	1354	3.77E+03	B	0.96	7.64E+03		2.90
5	1	Cd In<10	0.4801	207	2.36E+06	A	1.00	6.96E+07	7.35E+07	-5.33
	2	Cd In<10	0.4801	360	3.56E+05	A	1.00	7.44E+07		1.13
6	1	Cd In<10	0.4808	374	3.34E+05	B	0.96	8.02E+07		9.05
	2	Cd In<10	0.4808	211	2.35E+06	B	0.96	7.00E+07		-4.85
5	3	Cd In>20	0.4801	1370	2.46E+03	A	1.00	5.19E+03	5.30E+03	-2.06
6	3	Cd In>20	0.4808	1363	2.67E+03	B	0.96	5.41E+03		2.06
5	1	Cu	0.4403	224	1.15E+04	A	1.00	3.20E+04	3.14E+04	1.81
	2	Cu	0.4403	1408	3.90E+03	A	1.00	3.15E+04		0.30
6	1	Cu	0.4408	220	1.19E+04	B	0.96	3.17E+04		0.97
	2	Cu	0.4408	1408	3.92E+03	B	0.96	3.04E+04		-3.08
5	1	S	1.001	214	2.77E+03	A	1.00	2.78E+03	2.53E+03	9.95
	2	S	1.001	1434	2.01E+03	A	1.00	2.11E+03		-16.69
6	1	S	1.003	227	3.22E+03	B	0.96	3.11E+03		22.94
	2	S	1.003	1434	2.11E+03	B	0.96	2.12E+03		-16.20

Appendix B Beta Counting Results (continued)

2nd Exposure

CND	Count	Material	Unit wt	Delta T	dpm	Counter	Counter Correction	dpm/g @ T=0	Averaged dpm/gram @To	% Difference
7	1	Bare In<10	0.4802	231	8.53E+06	A	1.00	3.41E+08	3.91E+08	-12.61
	2	Bare In<10	0.4802	377	1.61E+06	A	1.00	4.19E+08		7.22
8	1	Bare In<10	0.4800	252	7.48E+06	B	0.96	3.77E+08		-3.52
	2	Bare In<10	0.4800	396	1.34E+06	B	0.96	4.26E+08		8.91
7	1	Bare In>20	0.4802	1389	2.19E+03	A	1.00	4.63E+03	4.77E+03	-3.00
8	1	Bare In>20	0.4800	1384	2.42E+03	B	0.96	4.91E+03		3.00
7	1	Cd In<10	0.4802	239	1.11E+06	A	1.00	4.92E+07	5.39E+07	-8.73
	2	Cd In<10	0.4802	389	1.77E+05	A	1.00	5.37E+07		-0.44
8	1	Cd In<10	0.4800	269	8.58E+05	B	0.96	5.37E+07		-0.43
	2	Cd In<10	0.4800	401	1.74E+05	B	0.96	5.91E+07		9.61
7	1	Cd In>20	0.4802	1395	1.43E+03	A	1.00	3.03E+03	3.03E+03	-0.25
8	1	Cd In>20	0.4800	1393	1.50E+03	B	0.96	3.04E+03		0.25
7	1	Cu	0.4393	257	6.86E+03	A	1.00	1.97E+04	2.06E+04	-4.27
	2	Cu	0.4393	1417	2.37E+03	A	1.00	1.93E+04		-6.03
8	1	Cu	0.4404	262	7.98E+03	B	0.96	2.21E+04		7.29
	2	Cu	0.4404	1417	2.70E+03	B	0.96	2.12E+04		3.01
7	1	S	1.003	268	8.53E+02	A	1.00	8.58E+02	6.84E+02	25.49
	2	S	1.003	1442	5.21E+02	A	1.00	5.46E+02		-20.17
8	1	S	1.004	277	7.12E+02	B	0.96	6.88E+02		0.61
	2	S	1.004	1442	6.40E+02	B	0.96	6.43E+02		-5.92

October 18, 2011

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**RESULTS FROM THE CALIBAN CRITICALITY ACCIDENT DOSIMETRY EXERCISE,
SEPTEMBER 2010 (U)**

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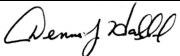
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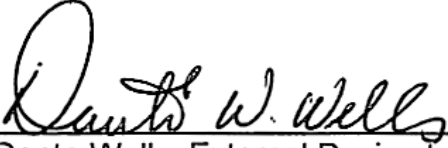
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**RESULTS FROM THE CALIBAN CRITICALITY ACCIDENT DOSIMETRY EXERCISE,
SEPTEMBER 2010 (U)**

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